HIGH-RESOLUTION ECONOMIC EVALUATION OF BLACK WALNUT ALLEY CROPPING AGAINST THE MAIZE-SOYBEAN ROTATION IN THE MIDWEST USA

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Abstract

The maize-soybean rotation (MSR) dominates the Midwest US and degrades many ecological functions. Black walnut alley cropping (AC) is an alternative land-use that can enhance productivity and restore ecosystem services. Given the lack of robust market mechanisms to monetize ecosystems services, we tested whether the profitability of AC could drive adoption in the Midwest. Publically available data on black walnut soil suitability, timber prices, crop productivity, and cash rents were combined in a high-resolution spatial analysis to identify target regions where these alternatives can outcompete MSR. We show that AC could be more profitable on 23.4% of cultivated land, assuming a 5% discount rate. The economic competitiveness of alternatives was not correlated with MSR productivity. Results reveal major opportunities for landowners and investors to increase profitability by investing in AC on both marginal and ideal MSR land.

Keywords: agroforestry; intercropping; silvoarable; discount rate; land-use; marginal land

Introduction

The maize-soybean rotation (MSR) is the dominant land-use in the Midwest US. Though extremely productive, MSR degrades many ecological functions (Foley 2005), is sensitive to future climate change (Mistry et al. 2017), and its profitability is volatile (Brandes et al. 2016). Alley cropping (AC), an agroforestry practice that grows crops in alleys between tree rows, is an alternative land-use that can enhance productivity and restore ecosystem services (Thevathasan and Gordon 2004; Jose 2009; Tsonkova et al. 2012). For example, AC can sequester substantial amounts of carbon (Udawatta and Jose 2012) and reduce nitrogen losses via nitrate leaching (Dougherty et al. 2009) and nitrous oxide emissions (Beaudette et al. 2010). While these environmental benefits can certainly increase landowners' interest in agroforestry (Winans et al. 2016), they have failed to drive adoption due to the lack of robust market mechanisms to monetize their value. Profit remains the central driver for adoption of sustainable agricultural strategies.

Alternative agricultural practices are typically targeted at so-called "marginal" lands, which have low MSR productivity and contribute disproportionally to negative externalities (Richards et al. 2014). However, there are strong economic opportunities for land-use alternatives across existing MSR land (Brandes et al. 2016). Here, we evaluate the economic competitiveness of one specific land-use alternatives: black walnut (*Juglans nigra*) AC. Merging high-resolution site suitability and profitability analyses enabled us to move beyond previous studies of coarse-scale profitability (Yemshanov et al. 2007; Frey et al. 2010) or basic site suitability at high resolution (Reisner et al. 2007; Wang and Shi 2015). Our dynamic black walnut growth model and high-resolution visualizations offer a novel, robust tool for landowners and investors.

Juglans is the most common tree genus in temperate AC, used in 34% of field experiments (Wolz and DeLucia 2018). Whether sold as veneer or less valuable sawlogs, black walnut commands higher prices than all other temperate timber species. Furthermore, black walnut is an ideal species for AC because of its short growing season, sparse canopy, large taproot, and deep rooting system. The economic competitiveness of AC depends on the productivity of black walnut relative to that of MSR. Land that is marginal to MSR may not necessarily be productive for a given land-use alternative.

Materials and methods

Publically available data on black walnut soil suitability (BWSI), timber prices, crop productivity (NCCPI), cash rents, and land cover were combined to identify target regions where AC can be a direct economic competitor of MSR without monetization of any environmental benefits or direct government assistance. Analyses were performed at a 10x10 m resolution and focused on existing MSR land ("cultivated land") in Missouri, Illinois, Indiana, and Ohio.

All analyses were performed at 10x10 m resolution using the National Soil Survey Geographic Database (gSSURGO). Cultivated land was identified using the 2016 Cropland Data Layer (CDL) created by the USDA NASS. Average cash rental rates of cropland for each county in 2008-2016 were obtained from USDA NASS. To estimate cash rental rate for each map unit in each county, we followed the method of Brandes et al. (2016) to scale county-level rent by an index of maize-soybean productivity.

To estimate the potential growth rate of black walnut on each soil map unit, we fitted a growth model to data from all publications measuring diameter at breast height (DBH) of field-grown black walnut. Growth curves were then scaled using BWSI (Wallace and Young 2008). Maize, soybean, and wheat yields for each county were obtained from USDA NASS. These three species are the most common species used in temperate AC experiments (Wolz and DeLucia 2018). To estimate the trajectory of alley crop yields following tree establishment, data from all temperate and subtropical AC studies that report relative yield of maize, soybean, or wheat were extracted from the catalog of AC literature developed by Wolz and DeLucia (2018).

Parameters supplied to the black walnut model in addition to the DBH trajectory were taken primarily from Godsey (2006), Yemshanov et al. (2007), and Schultz and DeLoach (2004). Initial stand spacing for AC was 3.4 x 9.8 m, which was the mean spacing of systems in the literature used to develop the alley crop yield trajectories.

The cropland rent ($R_{m,c}$) represents the average annual income received by a landowner from MSR operators for each map unit m in each county c. Black walnut AC is economically competitive with MSR when its profitability meets or exceeds the threshold of $R_{m,c}$. The long-term, heterogeneous cash flow of AC cannot be compared directly to $R_{m,c}$, but first must be converted into a homogeneous cash flow over the same period, or the annual equivalent value (AEV). For each map unit m in each county c, we solved for the threshold discount rate $TDR_{AC,m,c}$ such that $AEV_{AC,m,c}$ was equal to $R_{m,c}$.

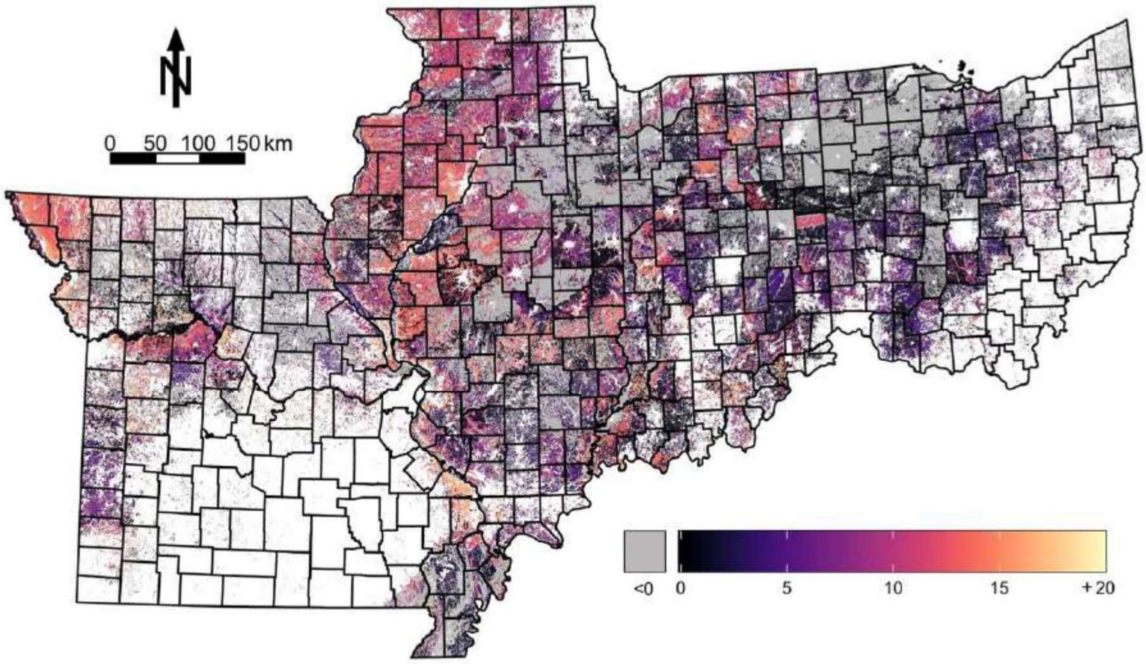

Figure 1: Distribution of the threshold discount rate (TDR_{AC}) at which the annual equivalent value (AEV) of AC and MSR are equal. Gray areas are cultivated land on which either BWSI = 0 or $TDR_{AC} < 0$. White areas are non-cultivated land.

Results and discussion

A total of 12 publications provided useable data on DBH of field-grown black walnut. Data spanned from one to 109 years after tree establishment, with DBH ranging from 0.5 to 58.3 cm. Mined literature provided relative yield data for a total of 93 site-crop-year combinations. Data spanned from 1 to 23 years after tree establishment, and relative yields ranged from 0.14 to 1.05. Maize, soybean, and wheat all exhibited significant declines in relative yield with tree age ($p < 0.01$). The largest yield declines were observed in maize, then soybean, and finally wheat with little yield reduction over time.

Black walnut AC (Figure 1) exhibited competitive TDRs in many regions across the four states studied. The higher the TDR, the more competitive AC is with MSR. Therefore, the percentage of cultivated land where AC outcompeted MSR (i.e. where AC has a higher AEV than MSR) increased with decreasing TDR (Figure 2a). The economic competitiveness of AC was not correlated with crop productivity (Figure 2b). Instead, cultivated land at the extremes of crop productivity contained the lowest proportion of land where AC was competitive.

Our results project strong economic competitiveness of black walnut AC with MSR. High TDRs were found on marginal and ideal MSR soils, confirming that the marginal land concept is inadequate in identifying target regions for AC. Instead, black walnut growth rate was the central driver of AC competitiveness. These results demonstrate that the soil suitability of alternatives is more important than MSR productivity in optimal land-use allocation. A shift away from the MSR-centric perspective in defining target regions for land-use alternatives is necessary.

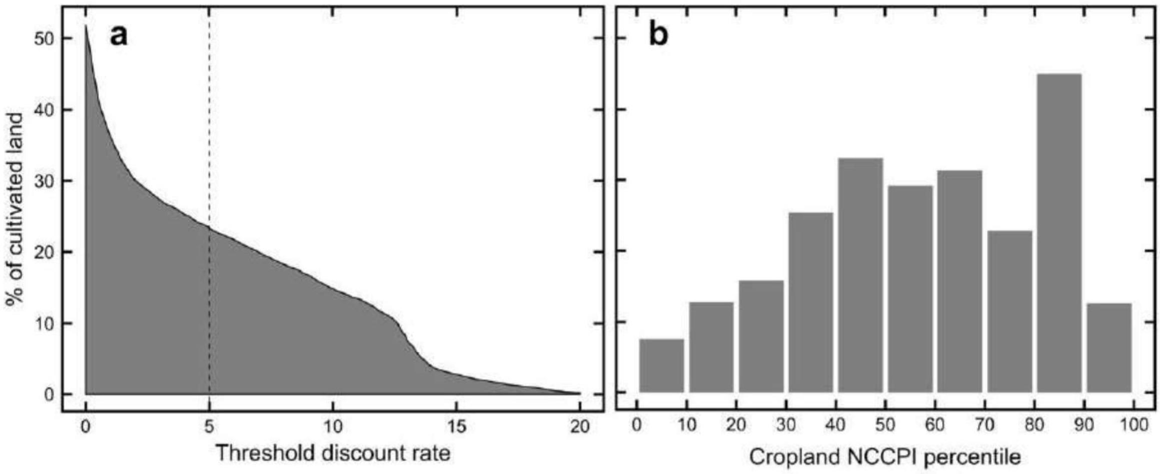

Figure 2: (a) Percentage of cultivated land as a function of TDR, on which black walnut AC has a higher AEV than MSR. The dashed line indicates a TDR of 5%. (b) Percentage of cultivated land in each NCCPI class on which black walnut AC has a higher AEV than MSR at a TDR of 5%. NCCPI classes are defined in terms of percentiles of NCCPI (e.g. the 0-10 NCCPI percentile includes the 10% of cultivated land with the lowest NCCPI).

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